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Thermal performance of parabolic concentrators under Malaysian environment: A case study

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ABSTRACT

Renewable energy generation is becoming more prevalent on today's electric grid. The challenges of increasing the percentage of renewable energy will be dealing with the intermittent nature of renewable sources. Three experimental models with various geometrical sizes and diameter of about 0.5 m of solar dish concentrators are used to analyze the effect of geometry on a solar irradiation and temperature and in maximising the solar fraction under Malaysian environment. These models are used to analyze the performance of parabolic concentrating collector's parameters such as reflector materials, aperture diameter, depth of concentrator, size of focal point and temperature at the focal point with different solar irradiations to increase the thermal efficiency. Thermal efficiency of the different dimensional dish concentrators are analysed using an absorber placed at the focal point. There is a significant variation in the efficiency of the concentrator with different reflective materials used. The efficiencies are calculated and results are conclusive. The 3 M Silverlux aluminium films are much efficient than stainless steel and increasing the area of the concentrator gives much more considerable variation in the results i.e. efficiency when comparing with the base. Overall, the efficiency of D_1 and D_2 is over 60% compared to D_3, which is 50% in many cases (by neglecting the losses).

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1. Introduction

Unfortunately, there is no control over the weather. Overcast skies can severely reduce the energy received on the ground. Obviously solar power generating plants are best located in regions with minimum cloud cover, dust and air pollution. For dimensioning a solar power generating system it is essential to know the number of hours of daylight expected at the site location. This can normally be obtained from national meteorological services and environmental research establishments. It helps even more if they are able to provide tables of expected solar energy for the region. The developments of CSP technologies have led to the continually increasing ability of these technologies to concentrate and harness solar energy for electricity production.

There exists of numerous techniques for the effective concentration of solar energy to produce this – solar thermal power – such as compound parabolic concentrator (CPC). The amount of energy collected by a solar thermal system depends upon the amount of sun light at which it is exposed. As the sun's position changes throughout the day and throughout the year, the solar system must be adjusted so that it is always aimed precisely at the sun and, as a result, produces the maximum possible power. Although, depending on the system configuration, most efficient systems require tracking of the sun either in one or two axes, so in this research, the calculated values of solar altitude and azimuth angles are used to track the sun accurately and orienting the solar dish concentrators. When the concentrator receives the sun's energy on the paraboloid surface and reflected it to the focal point, where all the energy is concentrated and collected.

There are 3 dishes involved which described as D_1, D_2 and D_3. D_1 is having depth of 5 cm, focal point of 26.45 cm and D_2 is having depth of 15 cm, focal point 10.42 cm. The reflective material of these 2 dishes is 3 M aluminium films while D_3 having stainless steel as a reflector with depth of 10 cm and focal point of 12.66 cm. The absorbers were fabricated from 85 cm length of copper tube of 4 mm in diameter spiralled and positioned at the focal point.

2. Potential of solar energy in Malaysia

The characteristic features of the climate of Malaysia are uniform temperature, high humidity, light winds and copious rainfall. Being an equatorial country, Malaysia has uniform temperature throughout the year [1] and the mean daily solar radiation in most places in Malaysia is in the range of 17–21 MJ/m^2 or 4.7–5.8 kWh/m^2 [2]. The annual mean temperature and the annual rainfall for Central Peninsular Malaysia are shown in Figs. 1 and 2, respectively [3,4]. The annual temperature varies from 26 to 28 °C while Malaysia is being one of the wet climate countries with as annual rainfall is approximately 2250 mm/year. However, it is extremely rare to have a full day with completely clear sky even during the severe drought period. The cloud cover cuts off a substantial amount of sunshine and thus solar radiation occur. On the average, Central Peninsular Malaysia receives 6 h of sunshine per day. This, however, is seasonal and spatial variations in the amount of sunshine received [1].

3. Comparison with research

Current work is based on the thermal performance of solar dish concentrators with different design specification under Malaysian environment, comparison between previous and current research are analysed. Although this kind of research is new in Malaysia, few countries have been done this research with the larger diameter of the dish concentrators. These results are compared in Table 1 and summarised as follows.

Kaushika and Reddy [5] having parameters of the dish concentrator are used satellite dish of 2.405 m in diameter with aluminium frame as a reflector to reduce the weight of the structure and cost of the system. The average temperature of water is 300 °C when the absorber is placed at the focal point and cost of this system is US$950. Nuwayhid et al. [6] was testing tracking parabolic concentrators at American University of Beirut, Lebanon. They have tested two dishes with diameter of 160 cm and stainless steel of 200 cm of aluminium and triangle slices of stainless steel mirrors as reflectors respectively. The cost of each dish concentrator is US$1540 with average temperature reaching up to 250 °C in aluminium dish and 350 °C in stainless steel dish.

Palavras and Bakos [7] used a damaged satellite dish of 2.85 m in diameter and a polymer mirror film as reflecting surface. The cost of this system is US$736 with average temperature reaching 300 °C. El Ouederni et al. [8] was testing parabolic concentrator of 2.2 m in diameter with reflecting layer having reflecting coefficient of 0.85. The averaged temperature in the system is 380 °C.

Through the Monte Carlo technique and optical properties, Shuai et al. [9] proposed new receiver design and modelling guideline based on the uniformity performance of the wall flux. They have shown that different cavity geometries provide significant variations on the overall flux distribution. Lovegrove et al. [10] have tested a new design of a 500 m^2 concentrator with 13.4 m focal length and altitude–azimuth tracking systems, which uses 380 identical spherical 1.17 m × 1.17 m mirror panels, that incorporated the Glass-on-Metal Laminate mirrors. However, extensive measurements have yet to be been done but the most notable feature is the very high concentration levels, with a peak of 14,100 with respect to the distance of the focal plane.

The model proposed by Folaranmi [11] was steam generator from a parabolic dish concentrator. Using this collector, heat from the sun is concentrated on a black absorber which is placed on the focal point of the dish concentrator. Water is heated at very high temperature to form steam. The model arrangement is mounted on a hinged frame supported with a slotted lever for tilting the parabolic dish reflector to different angles. This will make the sun always directed towards the collector at different period of the day. The test results from this model shows temperature above 200 °C on average sunny and cloud free day.

Three dish concentrators of various parameters were tested for current work. Two dishes are made Acrylonitrile butadiene styrene (P400 ABS) and other one from stainless steel. It is worth to mention that the intention of having the previous research included in this work is solely to provide some ideas and basic comparisons from the geometrical data and the cost involved, without taking into account the performance from each work. It is very difficult indeed for having a direct comparison due to the fact that too many variables that needs to be considered, as detailed out in Table 1.

4. Solar geometry and tracking

Basic of solar geometry can be found in several excellent texts on solar energy [12]. Two most commonly used configurations in two-axis sun-tracking system are azimuth-elevation and tilt-roll (or polar) tracking system. Inspired by an ordinary optical mirror mount, azimuth-elevation system is among the most popular sun-tracking system employed in various solar energy applications [13–16]. In the azimuth-elevation tracking, the collector must be free to rotate about the zenith-axis and the axis parallel to the surface of the earth. The tracking angle about the zenith-axis is the solar azimuth angle and the tracking angle about the horizontal axis is the solar elevation angle [17]. In a full tracking system, the solar collector tracks the sun in two axes such that the sun vector is normal to the aperture as to achieve 100% energy collection

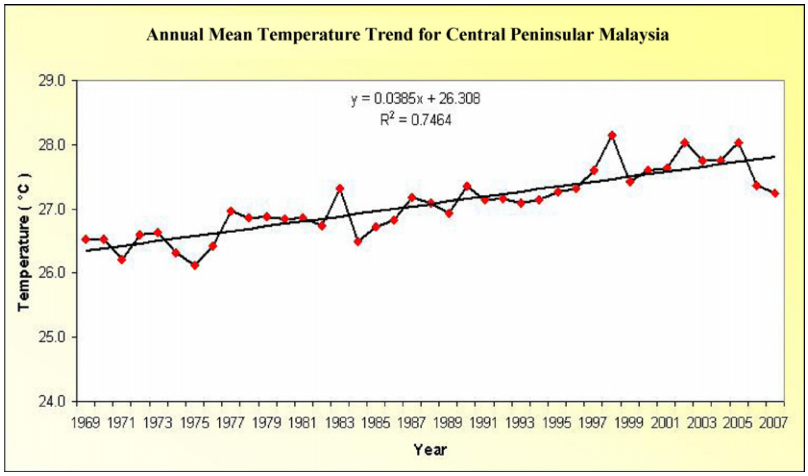


Fig. 1. Annual mean temperature trend for Central Peninsular Malaysia in 1969–2007 [3].

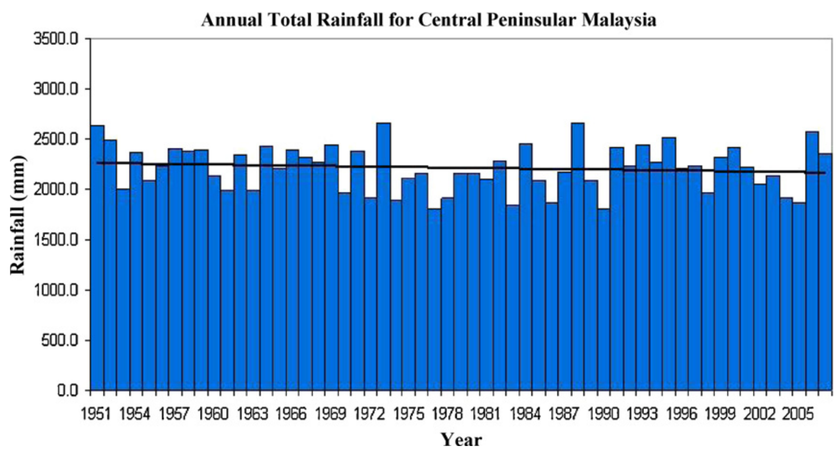


Fig. 2. Annual total rainfall for Central Peninsular Malaysia in 1951–2007 [4].

efficiency. In contrast, a partial tracking system only tracks the sun in a single-axis such that the plane of the sun's motion is normal to the aperture as to reduce the cosine loss [18,19].

The position of the sun is essential for many further calculations for solar energy systems. The two angles sun height, i.e. solar altitude or elevations (γ_ζ) and solar or sun azimuth (α_ζ) define the position of the sun as shown in Fig. 3. The sun height is defined as the angle between the centre of the sun and the horizontal seen by the observer. The azimuth angle of the sun describes the angle between geographical north and the vertical through the centre of the sun [20].

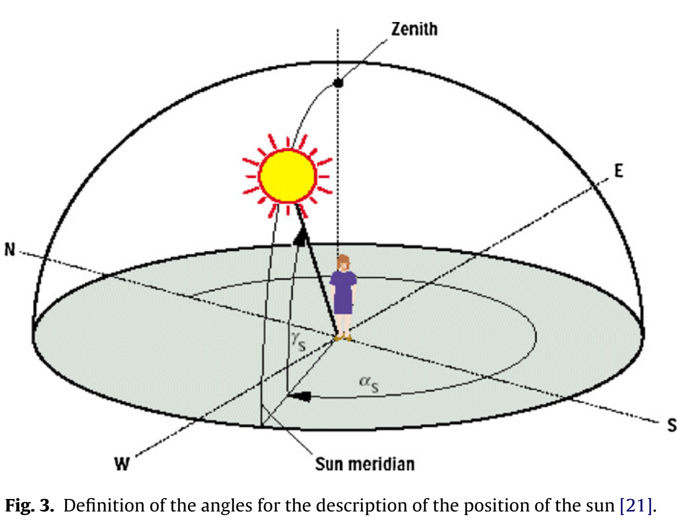


Fig. 3. Definition of the angles for the description of the position of the sun [21].

As a result of the earth's axial rotation and its revolution around the sun, the sun is constantly changing its position in the sky. This motion of the sun determines the amount of solar energy incident upon a collector located on the earth's surface. The area of a solar collector exposed to the direct solar radiation depends upon the angle between sun and the collector. Similarly, the length of time for collecting solar energy (day length) depends upon the sun celestial motion. The above variables are either time or location dependent. The time involved is the solar time, which describes the exact time of the sun with respect to the local time, for a given location where UPM, Serdang is considered in this work and is given by [6].

$$\text{Solar time} = \text{Standard time} + 4(L_{st} - L_{ioc}) + E \tag{3.3}$$

where L_{st} is the standard meridian for the local time zone, L_{loc} is the longitude of the location in question (in this case ITMA) and longitudes are in degrees west, that is $0^\circ < L < 360^\circ$. The parameter E is the equation of time in minutes and given by

$$E = 229.2(0.000075) + 0.001868\cos B - 0.032077\sin B - 0.014615\cos 2B - 0.04089\sin 2B \tag{3.4}$$

where $B = (n-1)360/356$ and n is the Julian day starting January first of the current year as unity [22].

Table 1
Comparison with some of the previous works.

	Works done by	Dish diameter	Reflector	Average temp.	Cost/US$	Comments
1	N.D. Kaushika, K.S. Reddy [5]	Used satellite dish of 2.405 m	Aluminium frame	300 °C	950	• Aluminium frame can be used to reduce the weight of the structure • Polymer film coated with a silver-aluminium alloy as reflector, which has less weight and reflection close to mirror • A solar to steam conversion efficiency of 70–80% at 450 °C, the collector system cost as US$ 225/m^2
2	R.Y. Nuwayhid, F. Mrad, and R. Abu-Said [6]	One piece of aluminium dish of 160 cm	Aluminium	250 °C	1540	• Aluminium surface needed to be machine polished in order to achieve higher concentration • This work shows that any university can set up a solar concentrator at a cost of US$750
		Stainless steel of 200 cm	Triangle slices of stainless steel mirror	350 °C	1540	• It has high reflection but some warping of the sheets was inevitable • Imperfect attachment of mirror sheets to mother dish
3	I. Palavras, G.C. Bakos [7]	Damage satellite dish of 2.85 m	Curved glass mirror abandoned due to high cost, weight and breakage Polymer mirror film of reflective coefficient of 0.85	300 °C	736	• Overall heat loss coefficient of approximately 163 W/m^2 K • This is due to flat aluminium plate absorber instead of a cavity receiver • Mirror films shows much improved performance The cost of this system is US$ 114/m^2
4	A.R. El Ouederni, A.W. Dahmani, F. Askri, M. Ben Salah, and S. Ben Nasrallah [8]	Parabolic concentrator of 2.2 m	Reflecting layer with reflecting coefficient of 0.85	380 °C	Not given	• The results could affirm that a good quality of industrial high temperature equipment can be obtained using this technology of sun light concentration
5	K. Lovegrove, G. Burgess and J. Pye [10]	Parabolic concentrator of 25 m	Curved glass mirror with 93.5% reflectivity (a total of 380 pcs of 1165 mm × 1165 mm)	Yet to be tested	Not given	• Massive in size (500 m^2) • Claimed to have very high concentration level of 14,100 at 13.4 m distance to focal plane
6	J. Folaranami [11]	Parabolic concentrator	Aluminium sheets	Above 200 °C	Not given	• This dish is very efficient heating equipment • When 1 kg of water was pouted inside the absorber boiling took place is less than 10 min
7	This Work	P400 ABS, 46 cm	3 M Silverlux Aluminium film	92 °C[a] 42 °C	570	Please refer Section 7
		P400 ABS, 50 cm	3 M Silverlux Aluminium film	97 °C[a] 45 °C	700	
		Stainless steel of 45 cm	Stainless steel	113 °C[a] 39 °C	404	

[a] Average temperature without the absorber.

Eqs. (3.3) and (3.4) involving all the solar angles such as declination, solar altitude and solar azimuth can be derived using Fig. 4.

$$\cos\theta = \sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\gamma + \cos\delta\cos\phi \cos\beta\cos\omega + \cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega + \cos\delta\sin\beta \sin\gamma\sin\omega \quad (3.5)$$

In addition, the incidence angle can be related to the solar angles by

$$\cos\ \theta = \cos\alpha_{\varsigma}\cos\beta - \sin\alpha_{\varsigma}\sin\beta\cos(\gamma_{\varsigma} - \gamma) \quad (3.6)$$

Solar declination δ is the angle formed by the line from the centre of the earth to the centre of the sun on a particular day and the plane containing the earth equator. The value of declination angle ranges

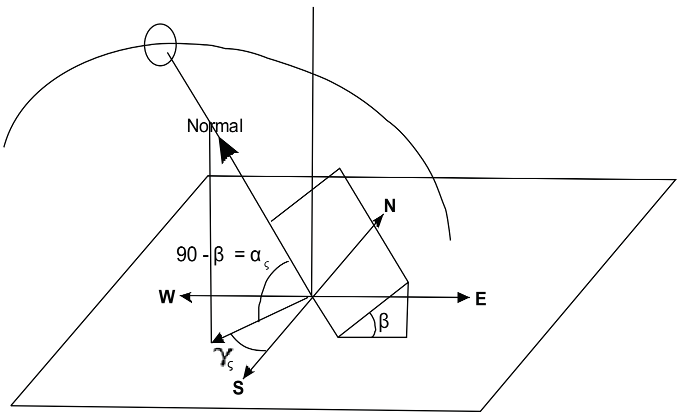


Fig. 4. Solar geometry for a tilted surface at a given location [6].

from 0° at the spring equinox, to +23.45° at the summer solstice, to 0° at the fall equinox, to 23.45° at the winter solstice [23]. Eq. (3.7) is used to calculate the solar declination. The declination for a given day (n) varies as 0

$$\delta = 23.45 \ \sin\left(360\frac{284+n}{365}\right) \tag{3.7}$$

Finally, the solar altitude (α_ς) and the azimuth angles (γ_ς) can be calculated using the following equations and sun's exact trajectory can be located.

$$\sin \ \alpha_\varsigma = \sin \phi \ \sin \delta + \cos \phi \ \cos \omega \ \cos \theta \tag{3.8}$$

$$\sin \gamma_\varsigma = \frac{\cos \delta \ \sin \omega}{\cos \alpha_\varsigma} \tag{3.9}$$

where ϕ is the local latitude, ω and δ are functions of time.

These solar geometry equations are used in many journal papers and books for sun tracking [12,24,25]. On the other hand, orientation of permanent collectors, focusing of concentrating collectors and mode of solar tracking are major factors considered for availability of on solar energy [6,12].

5. Solar radiation

The solar or short-wave radiation is radiation originating from the sun, in a wavelength of 0.3–3 μm. Long-wave radiation is radiation originating from sources at temperatures near ordinary ambient temperatures and thus substantially all at wavelengths greater than 3 μm [12]. The utilisation of solar energy involves collecting surfaces at a variety of angles to the horizontal [26]. The spectrum of the radiation emitted by the sun is close to that of a black body at a temperature of 5627 °C [27]. About 8% of the energy is in the ultra-violet region, 44% is in the visible region and 48% is in the infra-red region. The solar constant I_0 is the beam solar radiation outside the Earth's atmosphere when the sun is at its mean distance from the Earth. Its value is $I_0 = 1.37 \pm 0.02$ kW/m^2 [27].

Variations in the distance of the sun from the Earth due to the ellipticity of the Earth's orbit cause the actual intensity of solar radiation outside the atmosphere to depart from I_0 by a few percent. The processes affecting the intensity of solar radiation that are important in solar energy work are scattering, absorption and reflection. Reflection occurs in the atmosphere and on the Earth's surface. The scattering of solar radiation is mainly by molecules of air and water vapour or by water droplets or by dust particles. This process return 6% of the incident radiation to space, and 20% of the incident radiation reaches the Earth's surface as diffuse solar radiation.

6. Research methods and physical parameter of the dishes

The challenge to make best use of the immune, but diffuse, energy of the sun goes on. Concentration to raise the quality of incident solar energy is a route that has been pursued but has yet to show promise [6]. This section will focus on the methodology of the research and the parameters that involved in the current work. Fig. 5 shows the flow chart involved in this work.

7. Design parameters and fabrications

The aim of this research is to analyse the effect of solar geometry on solar irradiation and thermal performance of solar parabolic concentrators by making the D_3 as a base which is stainless steel dish concentrator having diameter of 45 cm and depth of 10 cm. The word collector will be applied to the total system, including the receiver and the concentrator. The receiver is the element of the system where the radiation is absorbed and converted to some other energy form; it includes the absorber, its associated covers, and insulation. The concentrator is the part of the collector that directs radiation on the receiver. The aperture is the opening through which the solar radiation enters to the concentrator [12]. The parameters involved in the experiments are given in Fig. 6.

7.1. The dish and shape

Concentrators are usually either two- or three-dimensional types, with the one-dimensional type being the familiar flat plate thermal collectors. In two-dimensional concentrators (parabolic troughs) the focus is a line, whereas for a three-dimensional (the parabolic dish and heliostat system) the focus is a point [6].

There are three paraboloid dishes to be used in the experiments. Those are 3D concentrators made of different types of materials and reflectors. Two dishes fabricated using Acrylonitrile Butadiene Styrene (P400 ABS) canister [28] and supported firmly with a rigid frame and other one is a stainless steel frame. It is made, such a way that its size and shape would form a point focus when exposed to sun in the normal direction. Dish models are designed such a way that it has different diameters and depth, where D_1 is having diameter of 46 cm with 5 cm in depth and D_2 is having diameter of 50 cm with 15 cm in depth. The main parameter of base concentrator D_3 is a stainless steel dish concentrator having diameter of 45 cm and depth of 10 cm. In this work, reflective materials used in D_1 and D_2 are 3 M Silverlux aluminium films and stainless steel in base concentrator D_3. Hence, the parameters involving 3 dishes will help to analyse the thermal performance of concentrators under Malaysian environment. Table 2 shows the design parameters of the three solar dish concentrators used in the research with the picture of D_1, D_2 and D_3.

The aims of the parabolic concentrators are to collect and direct the sun radiation of the low density to the small area, which increases several hundred times the density of the radiation. Increased solar radiation density is a prerequisite to its more efficient conversion into the electricity. The most important parameters that increase the quantity and density of the concentrated energy in the focus of the reflectors is concentrator projected area, secular reflection and accuracy of the reflector/mirror making. In practice, its own area, weight, and strength of the material and stiffness of the construction limit the size of concentrator. The greater the area of the mirror, the greater the weight will be and therefore, the greater the strain in material than the one allowed in case of strong wind [23].

One of the critical tasks in developing a solar concentrator is to identify a suitable and economical reflective material for this application. High-quality concentrators have their reflector

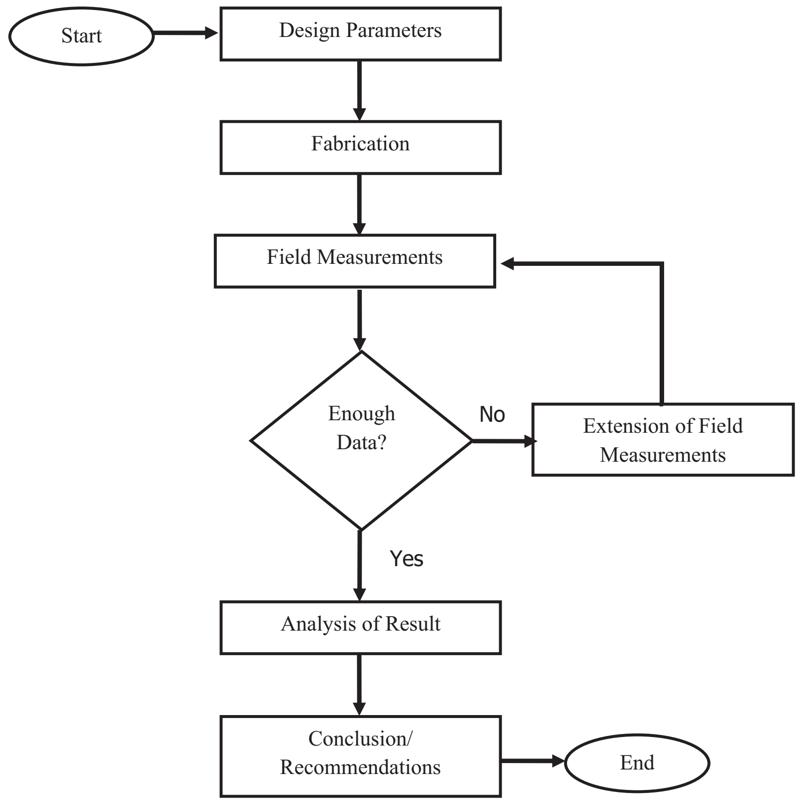


Fig. 5. Flow chart of the work.

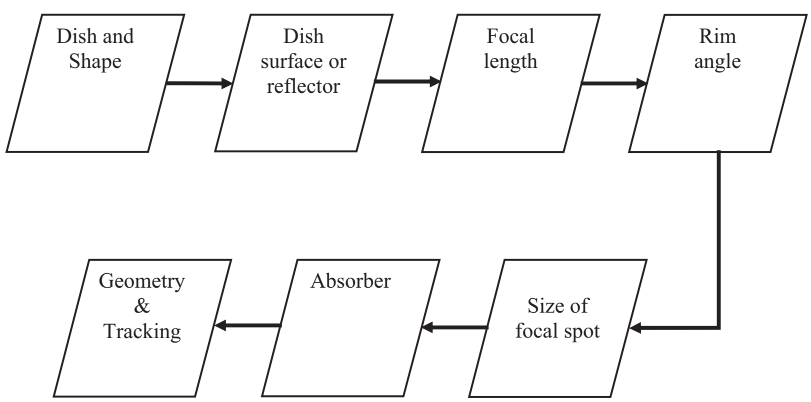


Fig. 6. Flow chart of designing solar collector.

Table 2
Dish concentrators parameters.

Parameters	Dish 1 (D_1)	Dish 2 (D_2)	Dish 3 (D_3)
Diameter, *D*	46 cm	50 cm	45 cm
Depth, *d*	5 cm	15 cm	10 cm
Dish material	P400 ABS	P400 ABS	Stainless steel
Focal point, *f*	26.45 cm	10.42 cm	12.66 cm
Aperture area	0.167 m^2	0.196 m^2	0.159 m^2
Reflector	Aluminium film	Aluminium film	Stainless steel
Tracking	Manual	Manual	Manual
Graphical picture			

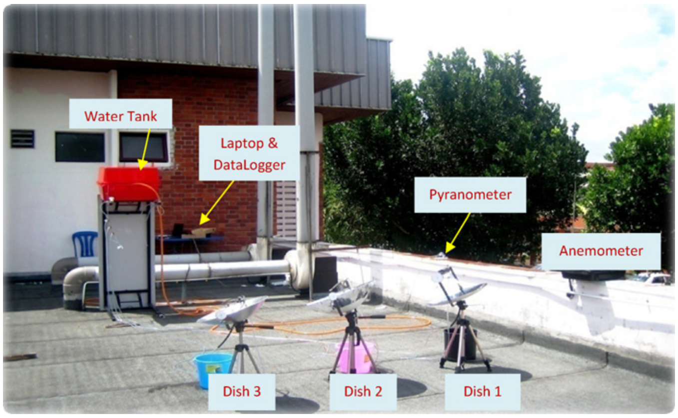


Fig. 7. The solar dish concentrators used in the experiment.

surfaces made of highly reflective materials such as mirrors and some metals with precision machining finishes. But these requirements may contribute to high initial cost. Fig. 7 shows the solar dish concentrators used to examine the solar concentrations. The reflector used in Dish 1 (D_1) and Dish 2 (D_2) are 3 M Silverlux aluminium films [30] while the Dish 3 (D_3), used a polished stainless steel. The curved concentrator having the aluminium film will give excellent paraboloid shape with light weight. In the second case, polished stainless steel surface dish concentrator is used as shown in Table 2, Like the aluminium film, polished stainless steel surfaces also have very high reflectivity [31].

7.2. Absorber

The Solar Thermal Energy Absorber essentially defines the overall configuration dimensions of the collector even if iteratively and starts off the design [32]. The heat transfer analysis that determines the inlet and outlet temperature of the fluid as a function of the length together with the other flow characteristics are measured along with the solar irradiation.

The absorber at the focal point receives the concentrated solar radiation and transforms it to thermal energy to be used in a subsequent process. The essential feature of a receiver is to absorb the maximum amount of reflected solar energy and transfer it as heat, with minimum losses, to the working fluid [5]. The absorbers were carefully designed such a way that it will minimize the energy loss due to the shading from the absorber. Three absorbers were fabricated from 85 cm length of copper tube of 4 mm in diameter spiralled and positioned at the focal point of each concentrator as shown in Fig. 8. The inlet and outlet of the water are running through one side of the receiver. The working fluid (tap water) in the storage tank is entering from the inlet then flowed through the spiralled absorber towards the outlet along the pipe. The heat transfer analysis that determines the inlet and outlet temperature of the fluid as a function of the length together with the other flow characteristics are measured along with the solar irradiation.

The temperature was measured using thermocouple wires with the flow rate of water. At different days flow rate is varied to analyze the variation in temperature of the water. Fig. 8 shows the absorber of D_1 used in the experiments.

7.3. Concentrator geometry and tracking mechanism

It is interesting to note that the suns positions are variable in during the day and different times of the year, so, it is necessary for the dish to point directly at the sun in order to maximise the solar energy collection and for highest efficiencies to be achieved. This can be carrying out by introducing a tracking system and there are more than one ways this technique can be performed. The tracking systems are classified by their motions. The first approach is to fix the concentrator and vary the receiver with respect to the variation of the focal point. This method is used in relatively large concentrators where it is awkward to manoeuvre the large and heavy system involved. A second method is to move the overall system, i.e. fixing the receiver with respect to the concentrator and tracking the sun as it moves [33].

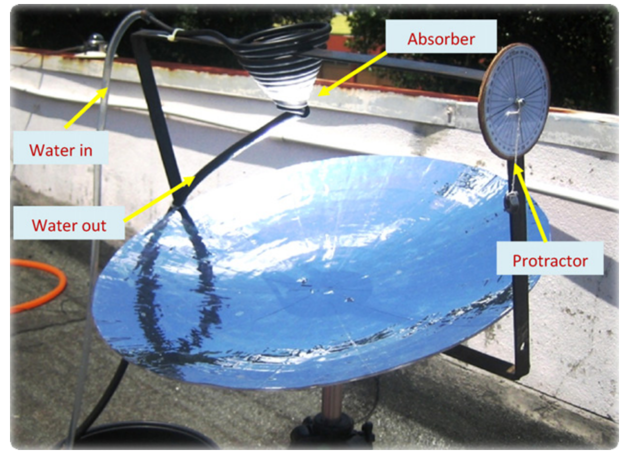


Fig. 8. Spiral copper coil used as an absorber.

The position of the sun in the sky relative to an observer on earth is defined by its altitude and azimuth angle. Every day the sun rises from the east with a zero altitude angle. The altitude angle increases until solar noon and after that it decreases, whereas the azimuth angle decreases up to solar noon and equals zero at solar noon. Afterwards the azimuth angle increases. The values of these two angles vary depending upon the location at a particular time of a day in a year [34]. In this work, when having small models of concentrators that can be moved easily, therefore, it does not have any tracking devices for concentrator rather used to track the sun's position manually by finding the altitude and the azimuth of the sun and tracking the sun's trajectory. The altitude and azimuth need to be calculated using the formulas in Section 4 and set separately at any instant of time and date. The website (http://sunposition.info) [35], which calculates the sun position with high accuracy, is used to find the altitude and azimuth angle. From these values, the concentrators are oriented towards the sun using a magnetic compass (azimuth) and protractor (altitude) as shown in Figs. 8 and 9, which represent the typical variation of solar altitude angle and solar azimuth angle for Kuala Lumpur on 28th August 2010 from sun rise to sunset.

8. Efficiency

In order to determine the system efficiency of the dish type solar concentrator, the optical efficiency and the thermal efficiency must be considered. The optical efficiency could be obtained using Eq. (3.12) [36,37], where P_a is the concentrated solar radiation intercepted by the receiver aperture, P_{mirror} is the solar radiation which is incident to the mirror or reflective aperture.

$$\text{Optical efficiency} = \frac{p_a}{p_{mirror}} \tag{3.12}$$

The collector thermal efficiency is defined as the ratio of the useful energy delivered to the energy incident on the collector aperture [38]. As mentioned before that the incident solar flux consists of direct and diffuse radiation and radiative heat loss is the collector surface reflection and emission [39]. The useful heat delivered by a solar collector is equal to the energy absorbed by the heat

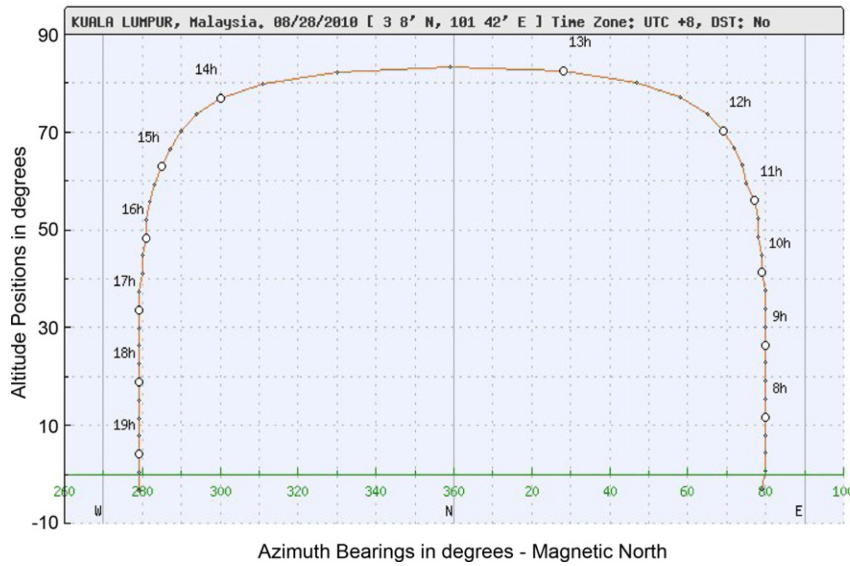


Fig. 9. Variation of solar altitude angle and solar azimuth angle for Kuala Lumpur [35].

transfer fluid minus the direct or indirect heat losses from the surface to the surroundings. When neglecting the losses the useful energy collected from a collector can be obtained from the following formula:

$$Q_{useful} = C_p \dot{m}(T_o - T_i) \tag{3.13}$$

where Q_{useful} is the rate of useful energy delivered by solar dish concentrating collector in W, C_p is specific heat at constant pressure in J/kg K, $\dot{m}$ is working fluid mass flow rate in kg/s, and T_i, T_o is temperatures of fluid entering and leaving the receiver in °C [9,40–42].

The collector thermal efficiency is also defined as the ratio of the useful energy delivered to the energy incident on the concentrator aperture and a function of water temperatures entering and leaving the receiver and the mass flow rate. Therefore, thermal efficiency can be determined in Eq. (3.14) [43].

$$\text{Thermal efficiency} = \frac{\text{useful workdone}}{\text{heat enegry supplied}} \tag{3.14}$$

Since the aperture area of the solar dish concentrator A_{ap} is a relevant indicator of the concentrated sun rays, the efficiency equation based on A_{ap}.

$$\eta_a = \frac{Q_{useful}}{I_{bn}A_{ap}} = \frac{C_p \dot{m}(T_o - T_i)}{I_{bn}A_{ap}} \tag{3.15}$$

where I_{bn} is the beam normal solar radiation in W/m^2 and A_{ap} is aperture area of the solar dish concentrator in m^2 [12,45].

9. Cost analysis

The total estimate cost of the dish collector system is shown in Table 3. The table includes the collector, absorber and other items that were used in the dish system such as iron bars and water hose. The total cost is thus anticipated to be no more than US$ 700.

Table 3
The cost of three dish concentrators.

Item	D_1	D_2	D_3
Collector	543	673	386
Absorber	7	7	7
Tracking	–	–	–
Misc	20	20	11
Total in US$	570	700	404

The higher price of D_1 and D_2 is due to the machining of concentrators using Acrylonitrile Butadiene Styrene (P400 ABS) canister at fabrication laboratory in ITMA. This material is very expensive material. If there were used or damaged dish available, there would be significant variation in the price of the concentrators.

10. Measurements and analysis

During the experiment, solar irradiation and temperature at the focal point have been analysed. In order to measure the temperature of the focal point, thermocouples were installed and irradiation was measured using the pyranometer with the help of DataLogger. Average ambient temperature of these days was taken to be 27 °C [44], note that the mean surface winds over Peninsular Malaysia are generally mild with the mean speed of 1.5 m/s, maximum speed of less than 8 m/s and gust speeds of less than 13 m/s are considered [45,46]. Fig. 10 shows the experimental process used with the absorber.

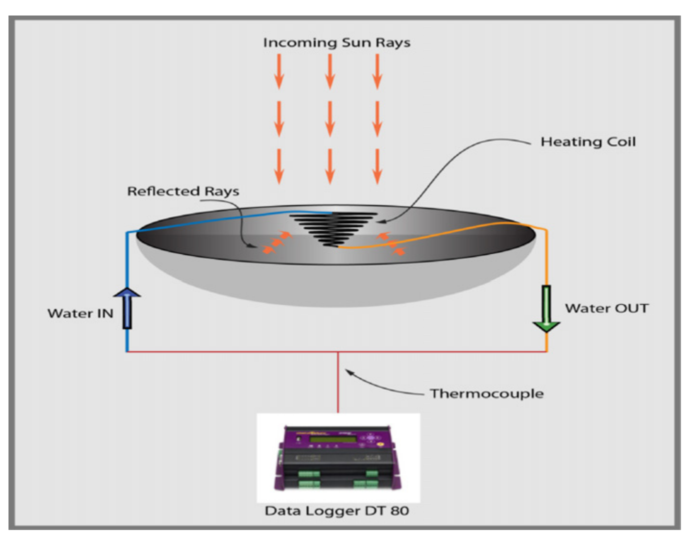


Fig. 10. Experimental process.

11. Conclusion

Like others [47–49], this study shows that ample resources exist in Malaysia for solar applications. In particular, the high levels of solar resource throughout the entire country make it well suited for solar dish technology or other solar thermal energies. Because of the general high level of cloudiness and humidity associated with tropical settings such as this the resources for concentrating solar power are generally less than adequate, except for certain times of the year.

The work presented is a simple exercise in designing, building and testing small laboratory scale parabolic concentrators. The medium of the reflector greatly influence the collector efficiency of the dish collector system and thermal efficiency of the system is determined using an absorbers placed at the focal point with water running it. The performance of the systems is efficient with the small aperture area of the dishes used in the experiment. The efficiencies of D_1 and D_2 are over 60% compared to D_3, which is 50% in many cases. The geometrical effect on solar dish concentrators were clearly shown in the results and greater thermal efficiency can be reached with the varying of the geometrical shapes of solar dish concentrators, especially with increasing the depth of the concentrator and efficient reflective materials. Furthermore, the results obtained in D_2 shows much more efficient compared to other two concentrators.

In recent decade, more and more research on solar energy helps to reduce the cost of operating cost, higher efficiency and environment friendliness in modern solar energy systems. Today, emerging new technologies and materials are placed into the market and many developed countries such as US and Spain, are offering strong support for new solar thermal energy projects. This would be an exciting time for the development of solar dish concentrator systems.

To increase the efficiency of the system the following improvements could be recommended:

- Enhancing the geometrical preciseness of the manufacturing.
- Using a reflective film with higher reflectivity and improving the pasting technology or using an anodised layer of aluminium technology so that the reflectivity could be increased.
- Using an efficient and more accurate tracking system.
- Finding the accurate focal point.

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